The Development of C-CORE's Seabed Coring Device

Denny Christian

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C-CORE
CENTRE FOR COLD OCEAN RESOURCES ENGINEERING
MEMORIAL UNIVERSITY OF NEWFOUNDLAND
ST. JOHN'S, NEWFOUNDLAND, CANADA, A1B 3X5
TELEX 016 4794 TELEPHONE (709) 737-8354

The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

Denny Christian
Engineering Technician
C-CORE

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ABSTRACT

C-CORE has designed and fabricated a remotely operated seabed coring device. The purpose of this coring device is to develop a relatively inexpensive method for penetrating medium to hard seabeds and recovering a representative sample. The core drilling method consists of rotating and pushing a double walled core barrel, with a liner to hold the sample, into the seabed. A drilling mud is used to flush the cuttings away and stabilize the core sample. The seabed corer is a self contained unit and can be operated from any moderately sized ship. This report deals with the principles of operation, the results of tests carried out with the sampling unit and suggests further developments to improve both operation and quality of sampling.

ACKNOWLEDGEMENTS

The design of the C-CORE seabed platform was the idea of Dr. John M. Jones, who developed the original concept of placing the core barrel in a kelly tube and forcing it down by means of hydraulic pressure. Mr. George Fowler of B.I.O. is thanked for his excellent advice in helping to solve many of our engineering problems. Dr. Pierre Morin, Mr. Vaughn Barrie, Mr. John Capps and Mrs. Eleanor Nesbitt-Friis are gratefully acknowledged for their critical reading of the manuscript. I would like to thank Mr. A. Pushpanathan for his mechanical engineering contribution and the Canadian Coast Guard and Mobil Oil Canada Ltd. who provided logistic support for the corer's sea trials. The contributions and technical knowledge given by the staff and supervisors of the Engineering Technical Services Department at M.U.N. are gratefully acknowledged as well as the effort of all those at C-CORE who helped in the preparation of this report.

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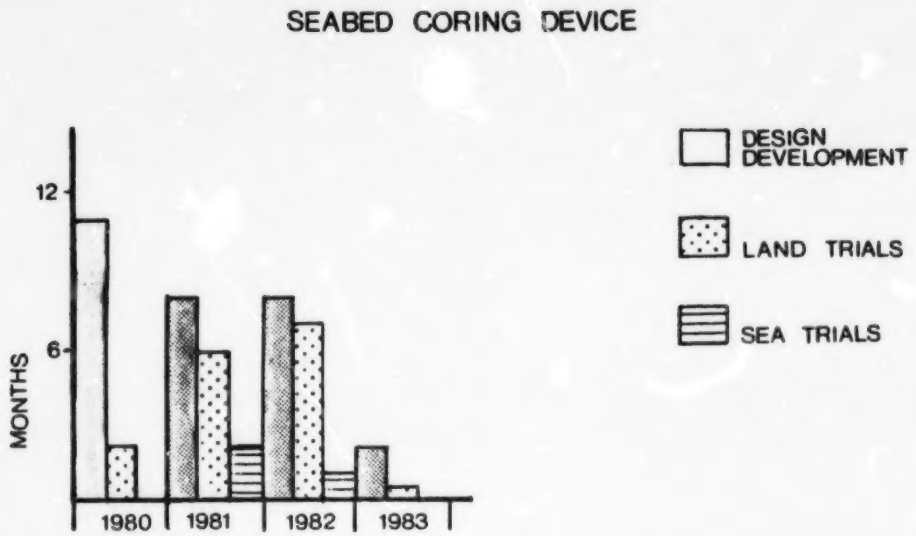
1.0 INTRODUCTION

Sampling of the seabed is required for a wide variety of scientific and geotechnical purposes. Engineering projects require geotechnical investigations for the construction of seabed foundations for offshore and coastal structures. Soil sampling provides data on the type of soil encountered, geological lithostratigraphy and biostratigraphy, chemical composition, and mineral composition; bedrock sampling provides information on the rock type and relevant structural properties.

Existing equipment such as gravity and piston corers, vibracorers, and grab samplers were unable to recover a sample from the seabeds encountered in many areas of the continental shelf on the east coast of Canada. Gravity and piston corers are mostly used to recover samples from soft unconsolidated soils. Good quality cores are limited generally to 2 metres of penetration, 20-25 cm of soil usually being recovered in sand or gravely sand (Sly, 1981). Although vibracorers can recover cores from sand, very little success has been achieved using vibracorers in stiff clay, gravels or in soils containing boulders. It is difficult to force a sampler into hard and brittle clay, dense cohesionless soil, or cemented soils without causing failure and disturbance of the soil before it enters the sampler (Hvorslev 1949). Grab samplers provide a quick method of obtaining surficial soil samples, but these samples are disturbed and they represent only the top few centimetres of the seafloor and may not be representatives of the bulk overburden (Ross, 1982).



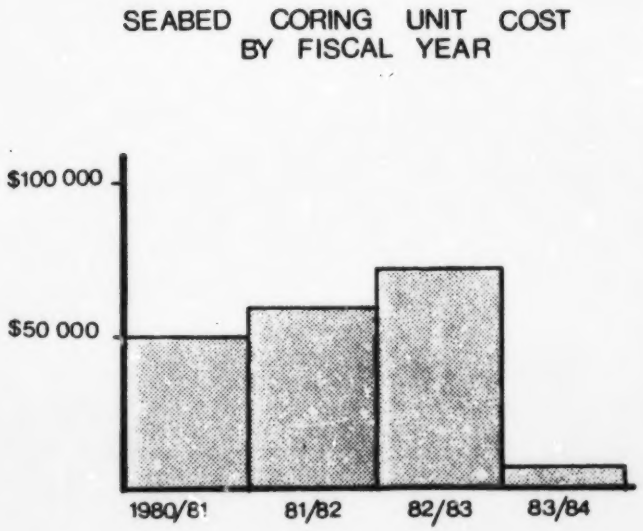


Figure 1 The Development of the Seabed Coring Device

At the present time, using specialized drill ships such as the **MV Pholas**, is the only suitable method of obtaining soil samples in these very particulate soils. These ships are equipped with a moon pool to facilitate a working platform and for instance have cored the hard compact seabed of the Grand Banks successfully. The core drilling method consists of rotating a double walled core barrel, with a liner, into the seabed using a tungsten carbide bit. An organic polymer drilling mud is used to flush the cuttings and stabilize the core sample and the hole. The cost of operating such drill ships is prohibitive for primary routine investigations.

Consequently, C-CORE initiated the design and fabrication of a seabed coring device in January of 1980. The purpose of this seabed sampling unit was to develop a relatively inexpensive method of penetrating the hard seabeds described earlier. The choosen solution was a remotely operated platform that could be operated from any moderately sized ship and that allowed for a penetration up to 4.5 metres. Figure 1 outlines the successive steps of the development of the seabed coring device in terms of time and cost. The principles of operation and the main features of the corer are described in this report. Limitations and improvements are also discussed.

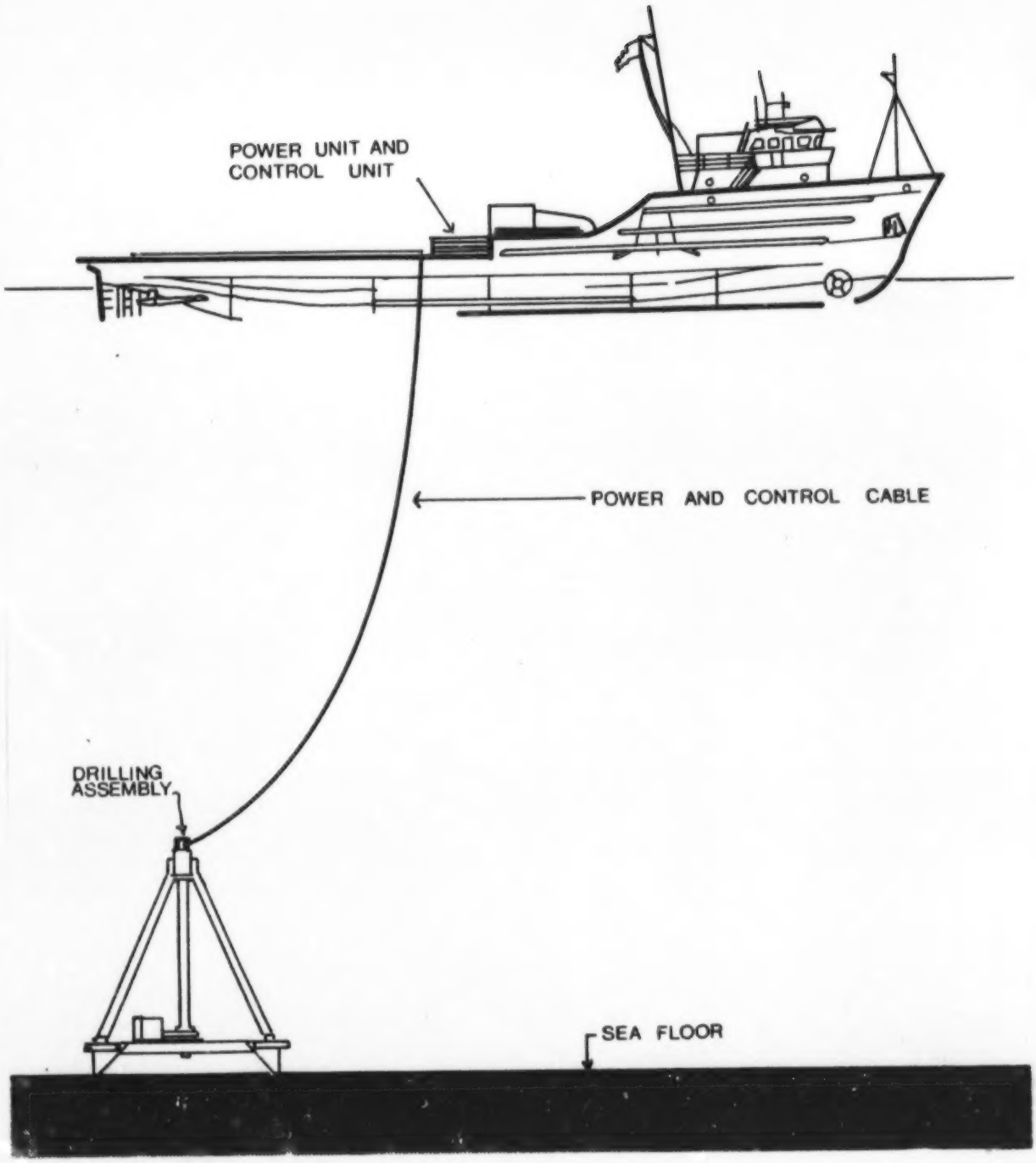


Figure 2 Remotely Controlled Seabed Coring Device

2.0 PRINCIPLES OF OPERATION AND DESIGN

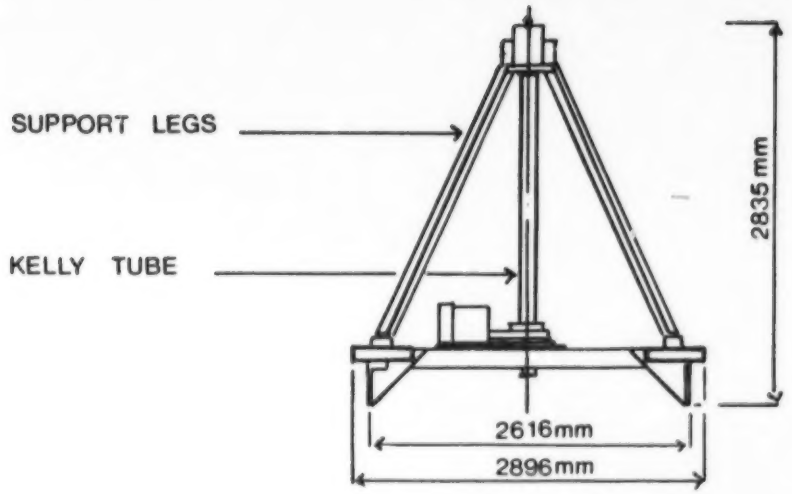
2.1 Remote Control

The C-CORE seabed drilling assembly consists of an open pyramid like frame which is lowered to the seabed from the operating vessel. This structure is free standing and connected to the operating vessel by power and control cables (Figure 2).

A generator located on the deck of the operating vessel supplies power to the drilling assembly. Two, three-phase, submersible electric motors are used for rotating the drilling column and driving the water pump. Both are controlled from a panel on the deck of the vessel.

Information from sensors on the drilling assembly is also transmitted through the umbilical cable to the control panel. The complete drilling operation is controlled and monitored from the vessel. Some problems, inherent to a remotely operated system, have been encountered. For example, it is difficult to deploy and retrieve the drill assembly in rough seas. Maintaining the ship relatively close to the drilling assembly while it is on the bottom can be very difficult in fast currents or strong winds.

On the other hand, a remotely operated system is a relatively inexpensive and quick method of obtaining drill samples compared to a specialized drill ship. The quality of the sample close to the mud line are better than those obtained by gravity or piston cores.



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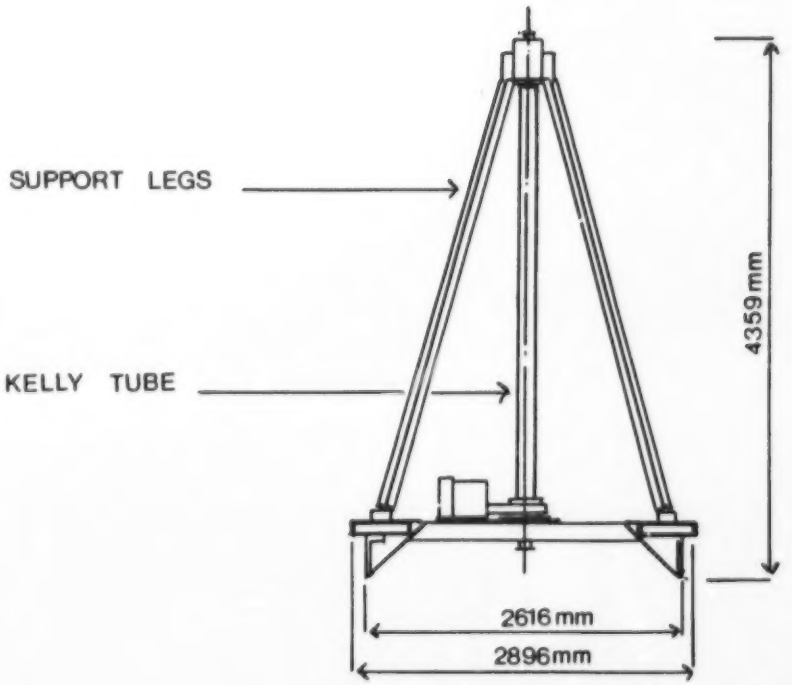


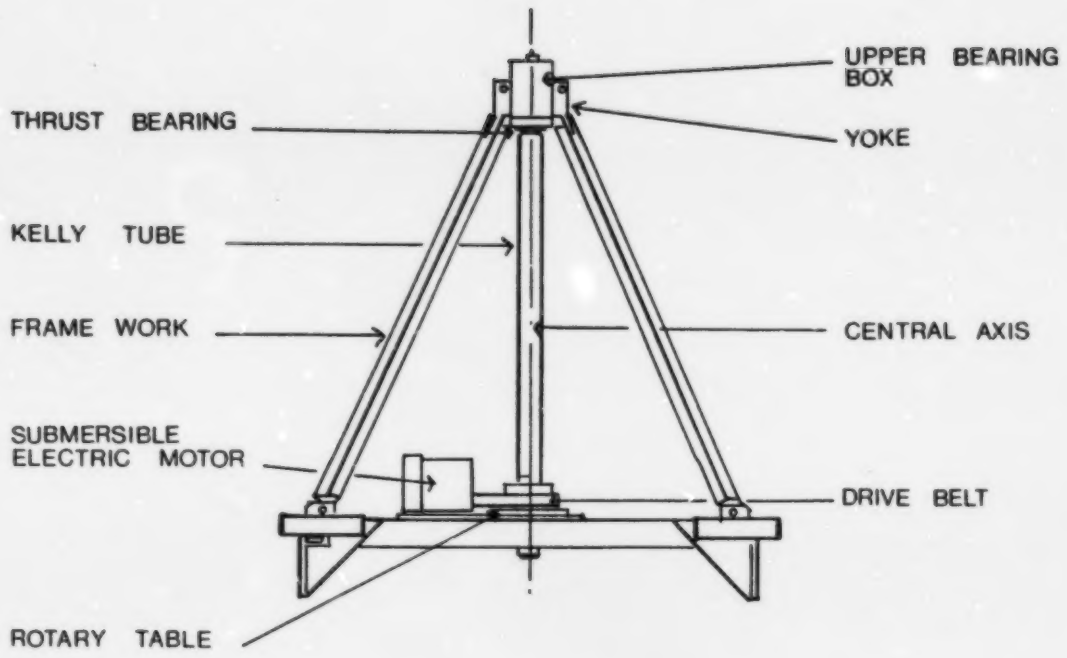
3.0 m CORER

Figure 3 Coring Devices

2.2 Reaching

The depth, or reach, to which the seabed coring device can drill is directly related to the height of the drill. The core barrel, located inside the kelly tube, is pushed and rotated into the seabed. When it has penetrated to its total length, the seabed drilling assembly is brought back to the ship so that the core can be recovered. It is not possible, therefore, to re-enter the same hole and continue drilling. The design of the seabed coring assembly allows for an extension of the reach by increasing the length of the kelly tube, core barrel and support legs.

The two versions shown in Figure 3 have both been extensively tested. Two hours are required to change from one assembly to the other. The small assembly will take a 1.5 metre core and the larger assembly one of 3.0 metres. A large assembly (4.5 metre core) is at the planning stage. The base for this larger assembly would have to be weighted to maintain stability of the unit. The base frame of the assembly is hollow and is designed to accommodate lead weights. An even higher unit would not be stable enough unless changes were made to the base dimensions. This could be accomplished by extending the outriger leg.



PLAN VIEW

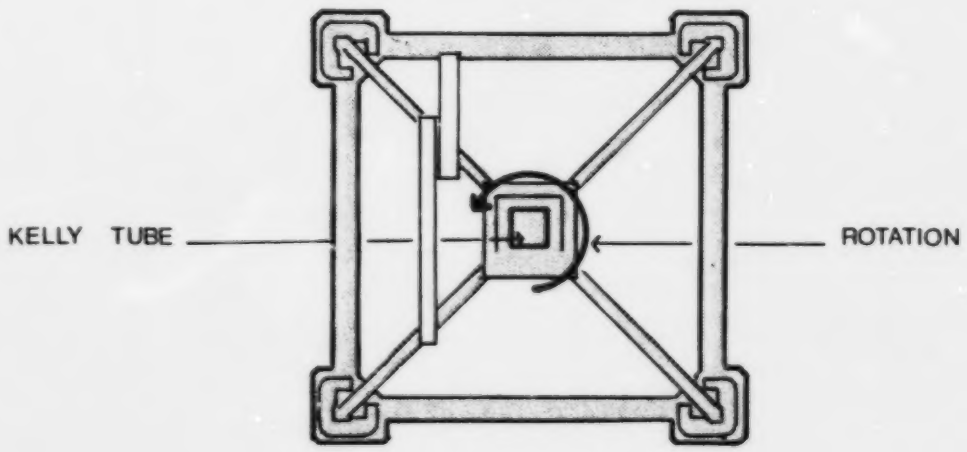


Figure 4 Layout of Seabed Coring Device

2.3 Drilling

It is difficult and sometimes impossible to vibrate or push a sampling tube into hard or brittle soils with a percussion hammer. If such soils are penetrated by vibrations or percussion the sample is disturbed before it enters the sampling tube. When course gravels or boulders are encountered by vibracorers or percussion hammers, the material is either pushed out of the way or penetration is terminated. On the other hand the appropriate rotary core bit, (usually tungsten carbides or diamond) will cut its way through these types of soils. As demonstrated hereafter, the right bit has to be selected in advance.

Core boring is not suited for sampling soft, loose fine material; better, thin walled samples can be obtained with stationary pistons. In slightly harder material, vibracorers are very efficient but if the thickness of the loose material is less than the length of the core barrel with a hard layer existing below, a rotary corer can penetrate into the hard layer. The loose material is held in the core barrel by the hard layer below it. There is little doubt that the rotary core boring appears to provide less disturbed samples in hard soils. The C-CORE Seabed Corer was designed, therefore, to sample hard layers or formations with boulders; the drilling method selected was rotary core borings.

The drilling and thrusting unit is mounted on the central axis of the framework perpendicular to the base (see Figure 4). The arrangement of this central unit, called the kelly tube, provides downwards thrust for penetration into the seabed and

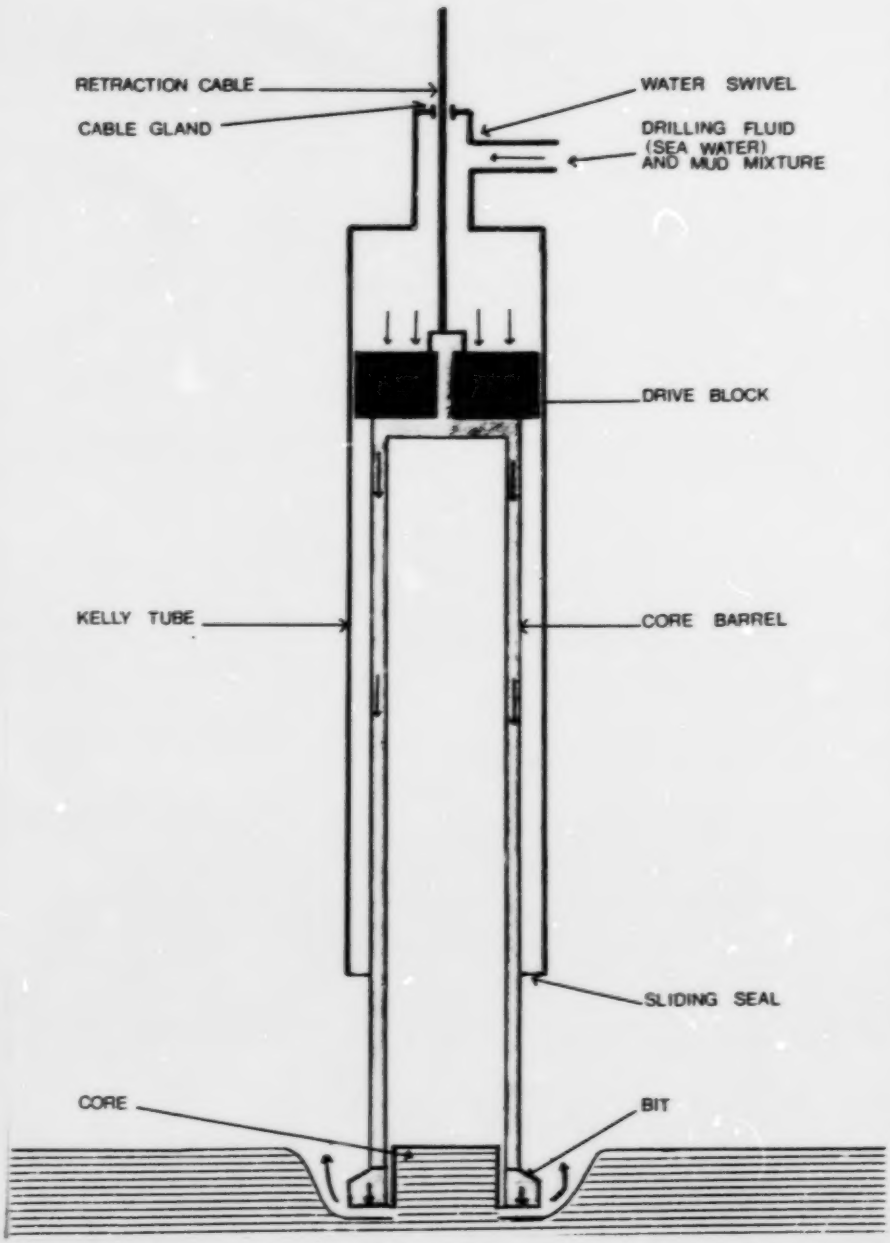


Figure 5 Kelly Tube

rotation for drilling. The kelly tube assembly, consisting of the trust bearing, water swivel, retraction cable gland, retraction cable and the core barrel, is mounted as a unit on the upper bearing box. This box rests in a three sided cradle or yoke and is held in place by two large pins. The thrust of the drill is transferred through the pins to the yoke and hence to the main frame. The removal of these pins allows the kelly tube to be lifted clear of the rotary table and swung away from the frame.

The kelly tube is suspended by the main thrust bearing at the top of the pyramid frame. The kelly tube passes loosely through a square hole in the rotary table which is mounted on the base of the frame. This table rotates the tube and a square drive block delivers the torque to the core barrel (see Figure 5).

The core barrel is mounted inside the kelly tube. This arrangement reduces the overall height to half that of conventional arrangements where the kelly drive and core barrel are coupled together. The core barrel is connected to the square drive block which rides inside the kelly tube. The kelly tube is closed at the upper end by a water swivel, and a cable gland; at the lower end a sliding seal is made between the inside of the square kelly tube and the outside of the round core barrel. When sea water is pumped into the upper end of the kelly tube through the water swivel, the water pressure, acting on the cross sectional area of the core barrel, produces an axial thrust forcing the core barrel out of the kelly tube. A portion of this

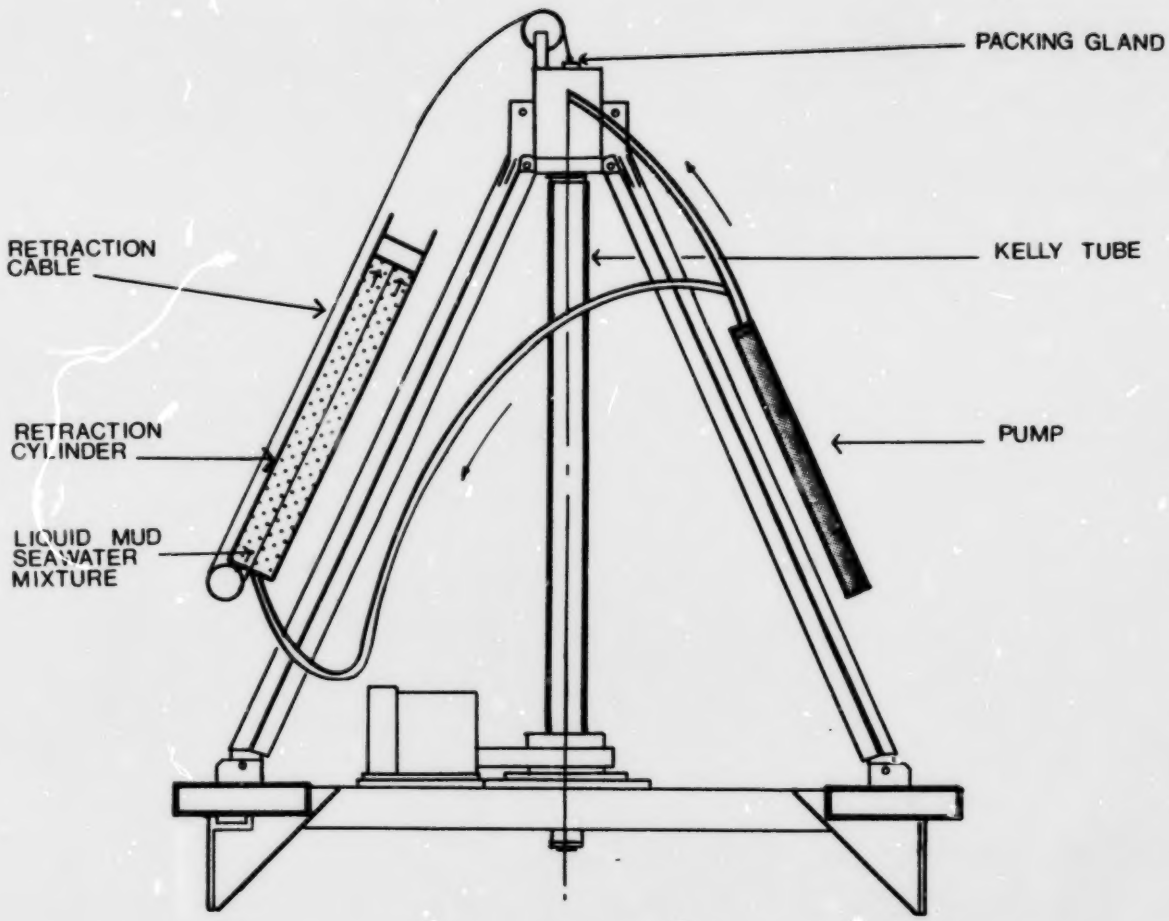


Figure 6 Hydraulic Retraction System

water is required to flush the bit and is regulated by a metering orifice located at the rear of the core barrel between the drive block and the core barrel.

The core barrel is retracted by activating a hydraulic cylinder which is connected to the core barrel by means of a cable (Figure 6). The cable enters the kelly tube through a packing gland and is connected to the back end of the core barrel by a swivel bearing. The bearing is necessary to prevent rotation of the retraction cable along with the core barrel.

2.4 Sampling

Rotary drilling requires a circulatory fluid to cool the bit and flush the cuttings away. To protect the core against the action of the circulating fluid double tubed core barrels are commonly used in sampling of soils and friable and soft rocks (Figure 7).

The inner tube may be connected rigidly to the core barrel head; in this case it rotates with the outer barrel and merely serves to protect the core against erosion and to keep the fluid passage open. The swivel head inner tubes are generally preferred, since the inner tube does not rotate during actual coring, and torsion is not transmitted to the core causing it to break.

The C-CORE seabed sampling assembly uses a Longyear triple-tube HV3 core barrel. This core barrel contains three tubes: an outer tube, an inner tube of the swivel tube type and a split tube inside the inner tube which holds the core. The split tube

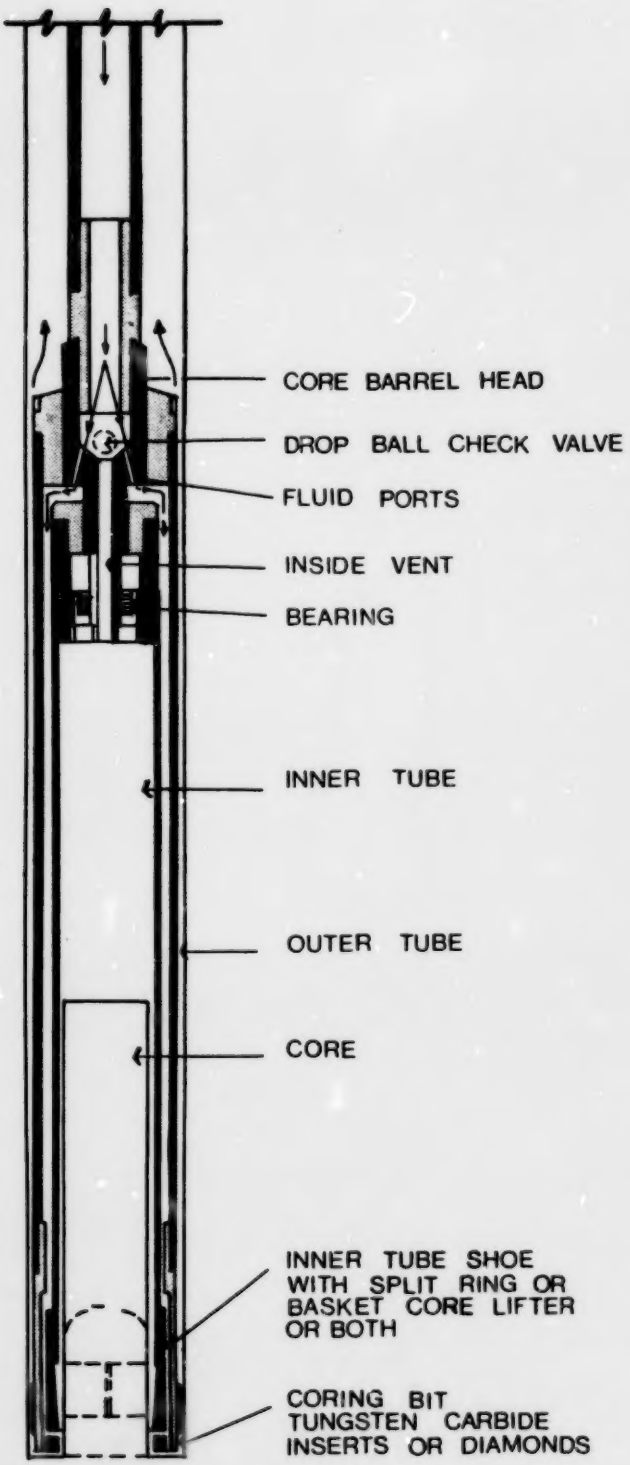


Figure 7 Double Tube Core Barrels

can be pumped out of the inner tube by utilizing a piston and water pressure at one end of the inner tube. Once the split tube has been pumped out the core can be obtained without disturbing the sample, by opening up the split tube .

A standard-inch plastic liner can be used in place of the split tube and it can be pumped out of the liner tube like the split tube. Cores can be sealed in the plastic liners for transportation or storage.

The actual grinding or cutting medium may be diamonds, tungsten carbide inserts, steel teeth or bladed or roller cutters. The shape of the bit and type and arrangement of the cutting media vary with the character of the material to be sampled.

The bottom discharge bit is used in soft broken rock and soil. The drilling fluid is discharged through the bottom of the bit which protects the core from being eroded.

The inner tube shoe contains a core retainer also called a core catcher or core lifter. In hard rock or stiff soil the core retainer used is a tapered and fluted split ring which grips the core after a short downward movement. In softer soil or sands a basket type core lifter is used to retain cores.

The back end of the inner tube has a vent and a check valve. The vent prevents the build up of hydrostatic pressure in the inner tube as the core enters; the check valve prevents the circulating fluid from entering the inner tube through the vent. The buildup of hydrostatic pressure in the inner tube could compress the core sample or prevent it from entering the inner

tube. The check valve also helps hold the sample in the inner tube when the core barrel is withdrawn.

Experience has shown that when drilling in soft material, sea water will wash the core sample away, even if a double walled core barrel is used with a bottom discharge bit. A drilling mud is introduced to the flushing water to control the washing effect on the core sample (Figure 8). The stabilizing effect of the drilling fluid is provided in part by its higher specific gravity in comparison with water alone, and in part by the formation of a relatively impervious coating or "mud cake" on the sides of the core sample and on the side walls of the borehole. This coating prevents sloughing of cohesionless soil and decreases the rate of swelling of cohesive soils. The slippery mud cake greatly reduces the friction between the core sample and the walls of the inner tube allowing the sample to move up into the inner tube with very little resistance.

A liquid mud, contained in a cylinder which houses a piston, is injected into the flushing water. Water is fed into the cylinder from the discharge side of the submersible electric pump. The water pushes the piston up, forcing the mud out of the cylinder into the intake of the submersible electric pump. The amount of mud entering the pump is controlled by regulating the flow from the cylinder containing the mud supply. The mud enters the pump and is mixed with the sea water as it passes through the impellers of the pump on its way to the drill bit.

2.5 Instrumentation

The drill is equipped with a penetration indicator, a tilt indicator and a pressure transducer. The penetration of the core barrel is monitored by running the retraction cable over a pulley. The pulley drives a system of magnets which in turn triggers a read switch. The read switch sends signals to a counter on the control panel which indicates the advance or retraction of the core barrel. The tilt indicator consists of two electrolyte sensors and is mounted on the frame of the drill. These sensors measure the angle at which the drill is sitting, on two different axis. The information from the sensors is transmitted to the control panel and provides continuous monitoring of any movement of the drill. The pressure transducer records the output pressure of the pump and therefore the force required to push the core barrel down. The hardness of the seabed is thus roughly monitored.

The operator of the seabed drill assembly evaluates its performance and operates it effectively from the data provided by these sensors.

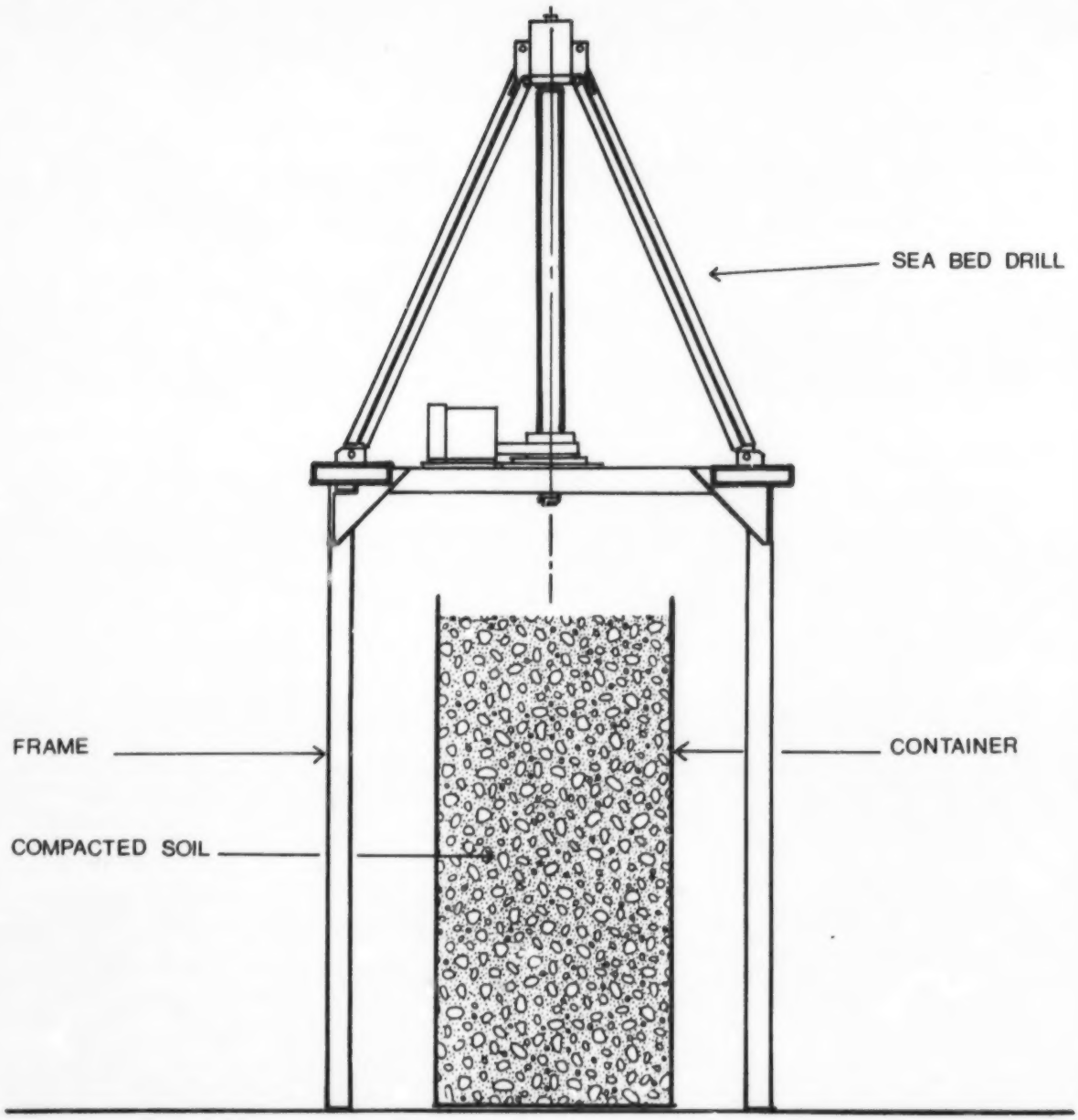


Figure 8 Laboratory Setup

3.0 LABORATORY TESTS

3.1 Introduction

Laboratory tests were carried out in the Structures Laboratory of Memorial University of Newfoundland. The drill was assembled in the 1.5 metre version. The drill was mounted on a solid frame that stood 1.8 metres above the laboratory floor. A cylindrical container ((0.6 metres in diameter and 1.5 metres high) was fitted with the material to be sampled and placed under the drill for the sampling operation (Figure 8).

In order to cool the submersible motor, the rotation motor of the drill was housed in a water jacket which was constantly supplied with water during the drilling operation. The submersible pump was placed in a tank beside the drill with a continuous supply of water for drilling. Fresh water was used for all the laboratory tests. The discharge side of the pump was equipped with a gate valve, a relief valve that could be set at various pressures and a pressure gauge.

3.2 Preliminary Tests

Tests 1 to 22 were carried out in the fall of 1980 and spring of 1981; they consisted of various mixtures of topsoil, sand and rock (see details in the Appendix C). The drum was filled with the soil mixture, 15 cm at a time, and the material was tamped to give near uniform hardness. The samples were placed under the drill and the container was bolted to the frame for drilling. All these tests were carried out using a face

discharge diamond bit. At this stage, no mud system was installed on the drill.

The purpose of these tests was to assess the drill's performance and to develop a drilling to procedure to obtain maximum core recovery in such soil samples. The drilling unit proved itself as a very efficient unit from an electrical and mechanical point of view.

The problems encountered in this series of tests were poor penetration in some cases and very poor core recovery. The poor penetration was mostly due to plugging of the bit or core barrel in the case of soil and sand samples, and rocks wedging in the bit, core catchers, and core barrel when sampling hard material. The diamond bit was also rotating on the loose, tumbling material diminishing the efficienty of the cut. The size of the flushing orifice at the back of the core barrel was varied to attempt to increase core recovery. Also two types of core catchers were tried to improve core recovery (the basket type soil catcher and the standard diamond drill rock core catcher).

The variation of the flushing orifice and core catcher produced good results in some specific soil types but a satisfactory core sample was not achieved. The results of these tests as well as further tests at sea (see sea trials) indicated that a number of modifications were required in order to obtain a satisfactory core sample.

3.3 Modification and Tests

Modifications were started in June of 1982 and continued with testing of the unit until November 1982. The first modifications were made to the retraction cable so that a better seal was obtained in the packing gland. The core barrel assembly was redesigned, and the mud system was added to the drilling unit (Figure 9). Laboratory tests were carried out during these modifications. The same set-up was used in the structures laboratory as on the earlier tests. The details of these tests are reported in Appendix C.

Pump tests were carried out, once the mud system had been installed, to establish what rates of flow and pressure different sized flushing orifices produced. After a number of tests it was established that a 3 mm flushing hole was the most suitable to core a large variety of soil samples. It was also found that the best penetration and satisfactory core recovery was obtained, at a pump pressure of around 200 psi.

The mud system was used during all these tests and it was constantly being developed and refined. Overall core recovery during the test was 63% with face discharge diamond bits and 62% with face discharge tungsten carbide bits. As the proper mud mixtures were developed and the proper bits, core catchers and drilling procedures were selected core recovery approached 90%. The tungsten carbide face discharge bit provides good results in sand and loose material. The coarse tungsten carbide cutting edge removes the material from in front of the cutting edge letting the core penetrate into the barrel with little

disturbance. This bit can also be used in harder material with slow advance rate. The face discharge diamond bit, seems appropriate for hard material. However, in soft or loose materials the diamond bit appears inefficient. Rotation of soil particles prevents a satisfactory cut and the material is compressed and plugged by the thrust of the bit.

Tests were also carried out on core catchers. Two types of core catchers were used, the soil catcher and a standard diamond drill rock catcher. Both catchers were tried in the barrel at once. It was found that the combination resulted in restriction of the sample. In loose material the soil catcher was found to be the best and in harder materials the rock catcher was more efficient. These tests have illustrated the fact that the right bit has to be selected for each type of soil in order to obtain satisfactory results.

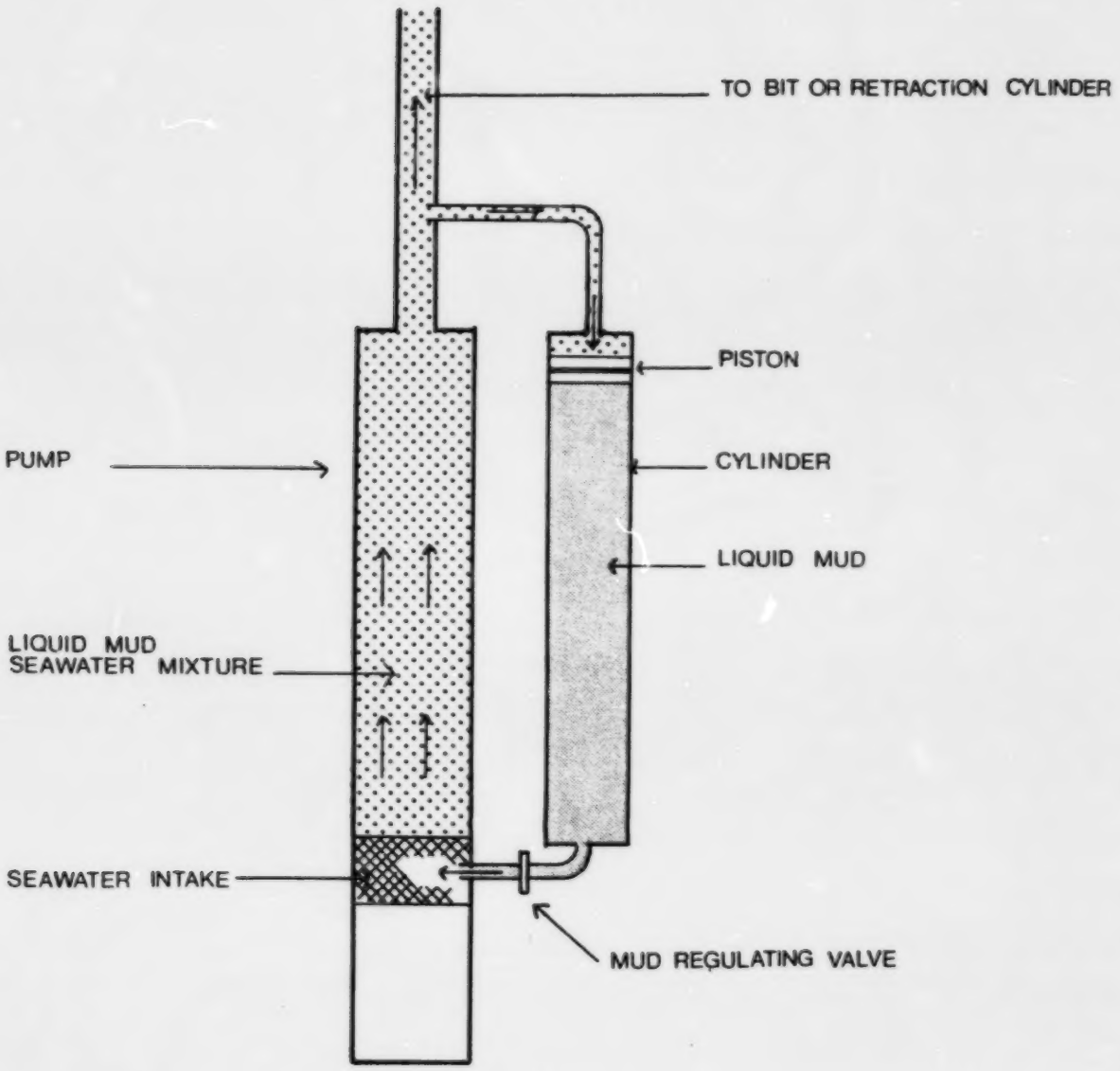


Figure 9 Mud Injection System

4.0 SEA TRIALS

4.1 C.C.G.S. Sir Humphrey Gilbert

The first sea trials in the summer of 1981 with the seabed drill were carried out from the **C.C.G.S. Sir Humphrey Gilbert** after laboratory tests which used water as a flushing fluid. The main purpose of these tests was to observe how the drill operated under water. The first test was carried out from the ship at Dominion Wharf, Bell Island. The drill was placed on the sea bottom and two divers observed the drilling operation. It took about 5 seconds for full penetration. The bottom consisted mainly of silt layers as far down as the drill could penetrate. No core was recovered.

The next three tests were carried out off Northern Bay Sands, Conception Bay. In that area, since the near bottom consists of sand and gravel with boulders, the first test used a Tungsten carbide face discharge bit. The drill ran for a short time and tripped out. The drill had penetrated a large boulder which returned to the ship with the drill. The bit had jammed in the boulder and stalled the drive motor by tripping it out on overload. A face discharge diamond bit was tried on the next two tests. A core of two feet of sand and gravel was recovered on the first test with the diamond bit. Another test was run with the diamond bit and a few pieces of gravel were recovered in the core catcher.

The drill ran well during the three tests off Northern Bay Sands. The actual depth of penetration was not accurately known

but it was assumed the reason for not having a longer core sample was that the sample was washing away.

4.2 Supply Boat Rovenstrum on Mobil Charter

The C-CORE drill had undergone testing in the laboratory and was ready for sea trials. The drill was taken on board the Supply Boat **Rovenstrum** as a backup for the Geological Survey of Canada's vibracorer that NORDCO was operating for Mobil Oil Canada Ltd. The C-CORE Seabed drill was tested on October 13, 1981. The drill had to be hoisted from the deck by a mobile crane and moved over the side of the ship. The load of the drill was transferred to a ship's winch to be lowered to the seabed.

The drill was lowered to the seabed in 77 metres of water and the drilling started. The electric motor's current ran at about 26 amps and slowly dropped to 17 amps. It was thought that the drill had stopped penetrating so it was returned to the ship. Only a few pieces of sand and gravel were recovered. A diamond bit had been used. An orifice plate with a 5 mm hole was used to control the flushing water.

The orifice plate was then reduced to 3 mm and the inner tube was adjusted so that there was more clearance between it and the bit. This was to make sure that the inner tube was not rotating with the bit. The drill was deployed at the same site in 77 metres of water. The drill started drilling at a current load of 23 amps and after twenty minutes it increased to 26 amps, 29 amps and 30 amps and finally it went to 35 amps and tripped out. The total drilling time was 30 minutes. The drill was

hoisted back on deck and a fifteen inch core consisting of sand and gravel was recovered.

The ship moved to a new site, and the drill was again deployed, in 93 metres of water. When the drill was started, the current drawn was 35 amps. In a minute it dropped to 25 amps and then it dropped gradually to 16.5 amps. This was not thought to be low enough to indicate that the drill has finished its penetration. It was run, therefore, for 43 minutes and then stopped. The drill was recovered and the core tube removed. Small pieces of stone were spread along 6 inches of the barrel.

Once again at this stage of design of this drilling unit it was not possible to tell how far the drill had penetrated. There was no indication of why the drill had tripped out on the second test. The increased core recovery on the second test was possibly due to the smaller flushing hole. On the third test the drill may have penetrated the length of the core barrel in a minute and spent the rest of the time rotating the barrel. The core may have shaken out over a period of time.

4.3 C.C.G.S. Bartlett

Sea Trials were carried out from the **C.C.G.S.Bartlett** off Board Harbour and Rushoon in Placentia Bay on November 27, 1982 and off the community of St. Mary's in St. Mary's Bay on December 2, 1982. The type of material encountered on these sea trials graded from silt, to sand to course gravel. The seabed characteristics encountered represent the worst possible material to core. The details of these tests are reported in Appendix D.

Sea water getting into the connectors that coupled the power cables to the rotation motor and the pump motor caused a ground fault and the motors were taken to Marystown Shipyard for repairs.

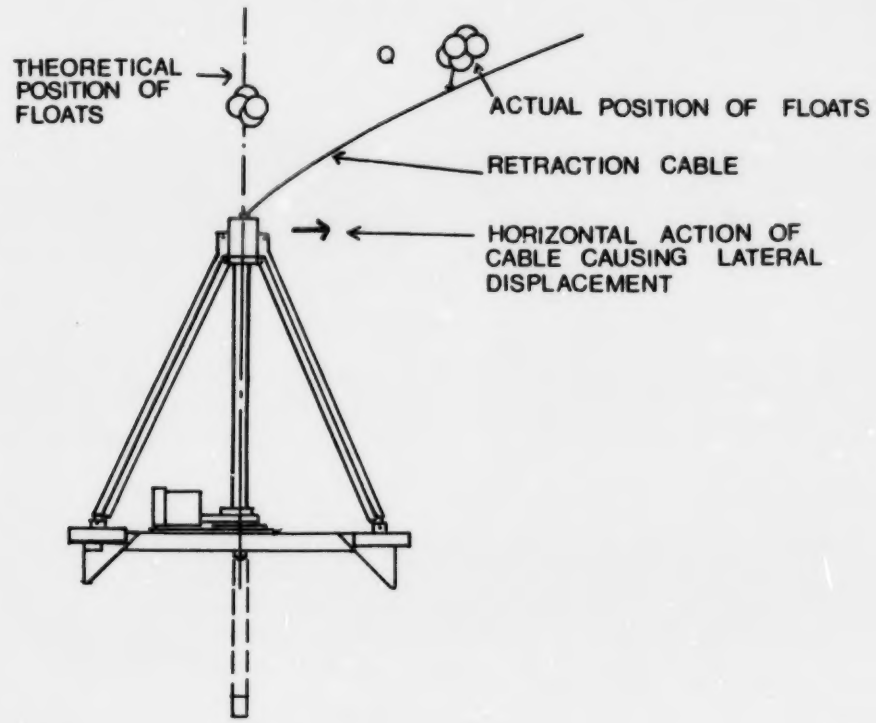
On November 27, three tests were carried out off Boat Harbour. A Longyear face discharge tungsten carbide bit was used on two of these tests and a Christensen tungsten carbide on the other test. At this time the drill was equipped with instrumentation to monitor the drilling operation on the seabed. Core recovery was poor and the penetration rate was also low. The mud system had frozen up during electrical repairs and was not working. The tilt indicators showed that there was considerable movement of the seabed frame during the drilling operation. A fourth test was carried out off Rushoon. The drill penetrated the full length but the core recovery was still poor. Again, the mud system did not work and the drilling platform was rocking.

On December 2, seven tests were carried out off St. Mary's. Two tests were carried out with the Longyear face discharge tungsten carbide bit and five tests with the Longyear face discharge diamond bit. A salt water ground fault was tripping the electric motors again. Despite these incidents penetration was generally good; core recovery was better but had to be improved. The mud system worked on all the tests but the mud was too liquid on the first two; the controlling orifice in the mud system was enlarged for the last five tests. The drilling frame was rocking during all these tests until a penetration of one

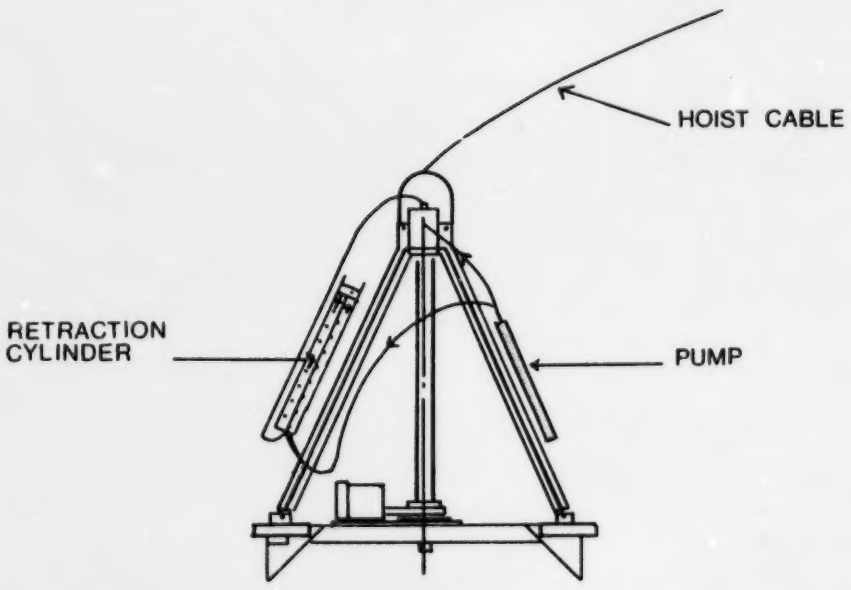
metre was [illegible]d.

These sea trials were the first indication of offshore operation. The drill proved to be a viable machine. It provides the proper torque and necessary downward thrust to penetrate the seabed. With the aid of the mud system, the core barrel can pick up and hold the core. The mud system does bind the sample reducing the washing effect of the flushing fluid and also the friction along the walls. The instrumentation package worked flawlessly and was found to be a necessary part of an efficient, monitored drilling operation.

It is thought that the stability problem was caused by the retraction cable feeding into the Kelly tube from the hoist cable. The retraction cable is always at an angle from the top of the pyramid frame. This exerts a force on the top of the pyramid frame causing it to rock. The weight of the hoist cable alone could cause the platform to move. Consequently, a retraction system has been installed on the drill to correct this problem. The hoist cable must be monitored during drilling to ensure that the cable is not applying too much force to the top of the pyramid frame (Figure 10). The drilling platform was then checked to see if there were any possible air locks in the frame which would increase its buoyancy and cause further instability. It is suspected that by means of this the last modification suitable core samples will be recovered.


THEORETICAL POSITION OF FLOATS
ACTUAL POSITION OF FLOATS
RETRACTION CABLE
HORIZONTAL ACTION OF CABLE CAUSING LATERAL DISPLACEMENT

ORIGINAL RETRACTION SYSTEM



NEW RETRACTION SYSTEM

Figure 10 Retraction Systems

5.0 CONCLUSIONS

C-CORE has designed and built a remotely operated seabed coring device that can be operated from any moderately sized ship. This platform rotates a triple tube core barrel down into the seabed to collect a core sample. The thrust to force the rotating corebarrel into the seabed is provided by hydraulic pressure created by a submersible electric pump which also circulates the flushing fluid for the drill bit. A drilling mud is introduced into the flushing fluid to stabilize the hole and the core sample. It prevents erosion of the core sample by the flushing fluid. The coring device is controlled and operated remotely from the deck of the vessel. Layers of soil and rock ranging from medium to hard strength can be sampled satisfactorily. The remotely operated seabed coring device is a relatively inexpensive method of sampling, compared to specialized ships, and if special precautions are taken, it is efficient in soils where other methods fail.

The depth to which the drill can penetrate is restricted to 4.5 metres. Nevertheless the platform has a wide range of applications for geological and geotechnical needs related to offshore development.

The rotary core drilling method combined with an appropriate mud system appears to be the best method of obtaining samples in medium to hard seabeds as long as the appropriate core barrel and drill bit are selected. Tungsten carbide bits are the most successful bits that have been used to core hard sand and gravels. More research is required in bit design and testing;

bits such as blade or roller cutter bits should be tried, in order to improve the efficiency of this seabed coring device.

The platform should be further developed to carry out other tests like vane shear test and penetration tests.

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APPENDIX A - SPECIFICATIONS

Longyear Triple-tube corer type	HV3
Core diameter	61 mm
Hole size	96 mm
Length of core	5 ft. (1.52 m) and 10 ft. (3.04 m)

Drill bits
a) Tungsten carbide, pilot crown, face discharge
b) Diamond bit, pilot crown, face discharge
45 carat 10 - 15 stones per carat

Drill power	11 kw (15 HP)
Pump motor power	3.7 kw (5 HP)
Maximum water pressure	2.96 MPa (430 psi)
Torque on drill	470 Nm (350 ft. lb)
Drill speed	223 rpm
Maximum thrust	2000 kg
Thrust at 20 gpm flushing rate (adjustable)	1,500 kg max.
Power supply	575 V, 3 phase
Method of power supply	(10-4) power cable from ship, 300m long
Power Source	Diesel generator on deck
Height	Core length + 1.52m
Weight	Approx. 2000 kg + ballast weights
Base	2.6 m x 2.6 m

Operating depth - typically 100 m - limitation set by difficulty of handling power cable on deck

Main support cable - wire rope from ship's winch

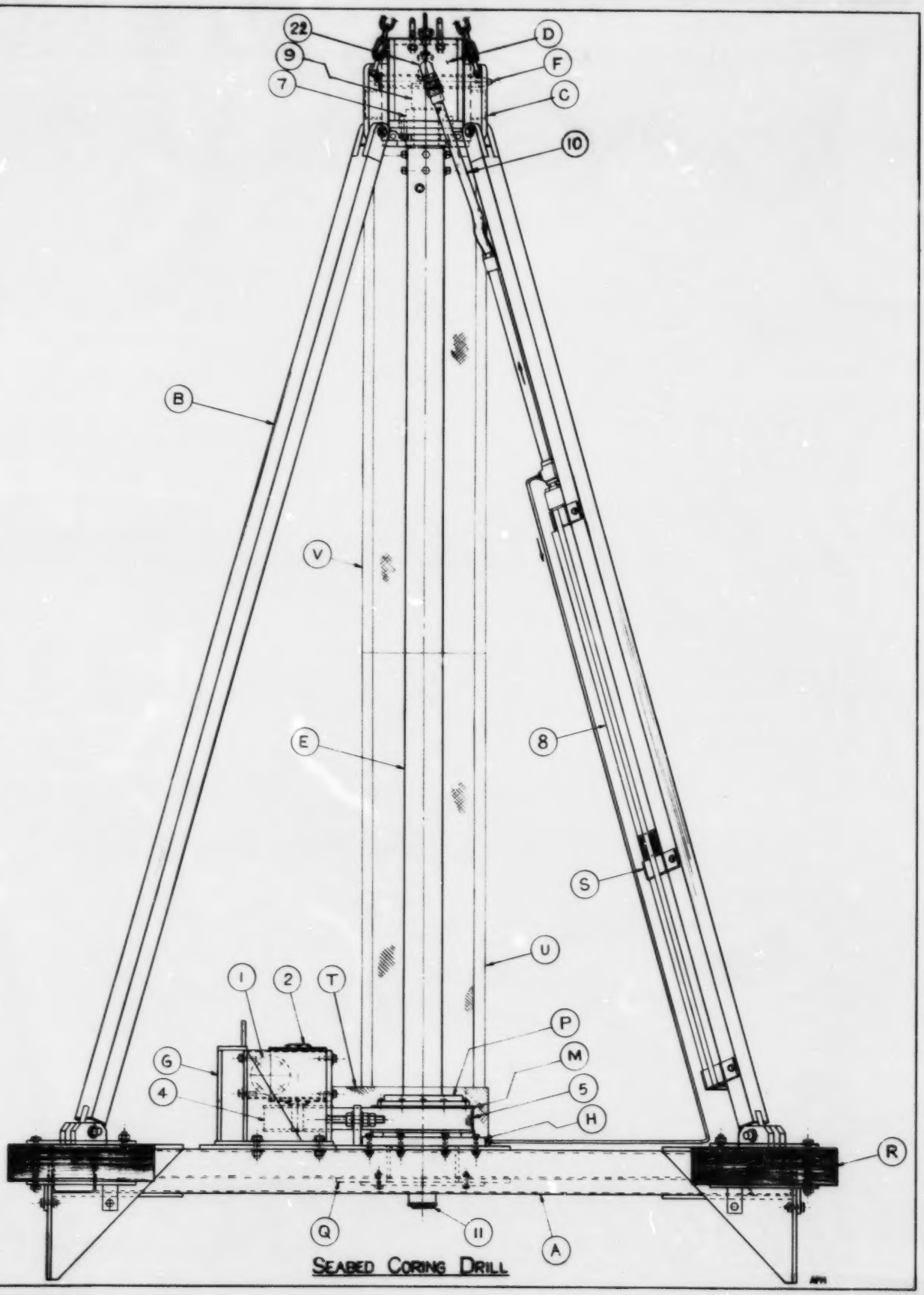
APPENDIX B

ENGINEERING DRAWINGS

SEABED CORING DRILL

1. Drive Motor
2. Gear Box
4. Sprocket
5. Belt
7. Bearing
8. Submersible Pump (GSW)
9. Water Swivel Assembly
10. Quik detachable coupling and hose assembly
11. Drill bit
22. Tie (1")

A. Base frame
B. Side members
C. Top bearing support cradle
D. Top bearing box
E. Kelly tube
F. Main support pins
G. Drive motor mount
H. Lower bearing fallen
M. Rotary table pulley
P. Kelly drive plate
Q. Rockshield
R. Fender
S. Pump support frame
T. Belt guard
U. Bottom kelly guard
V. Top kelly guard



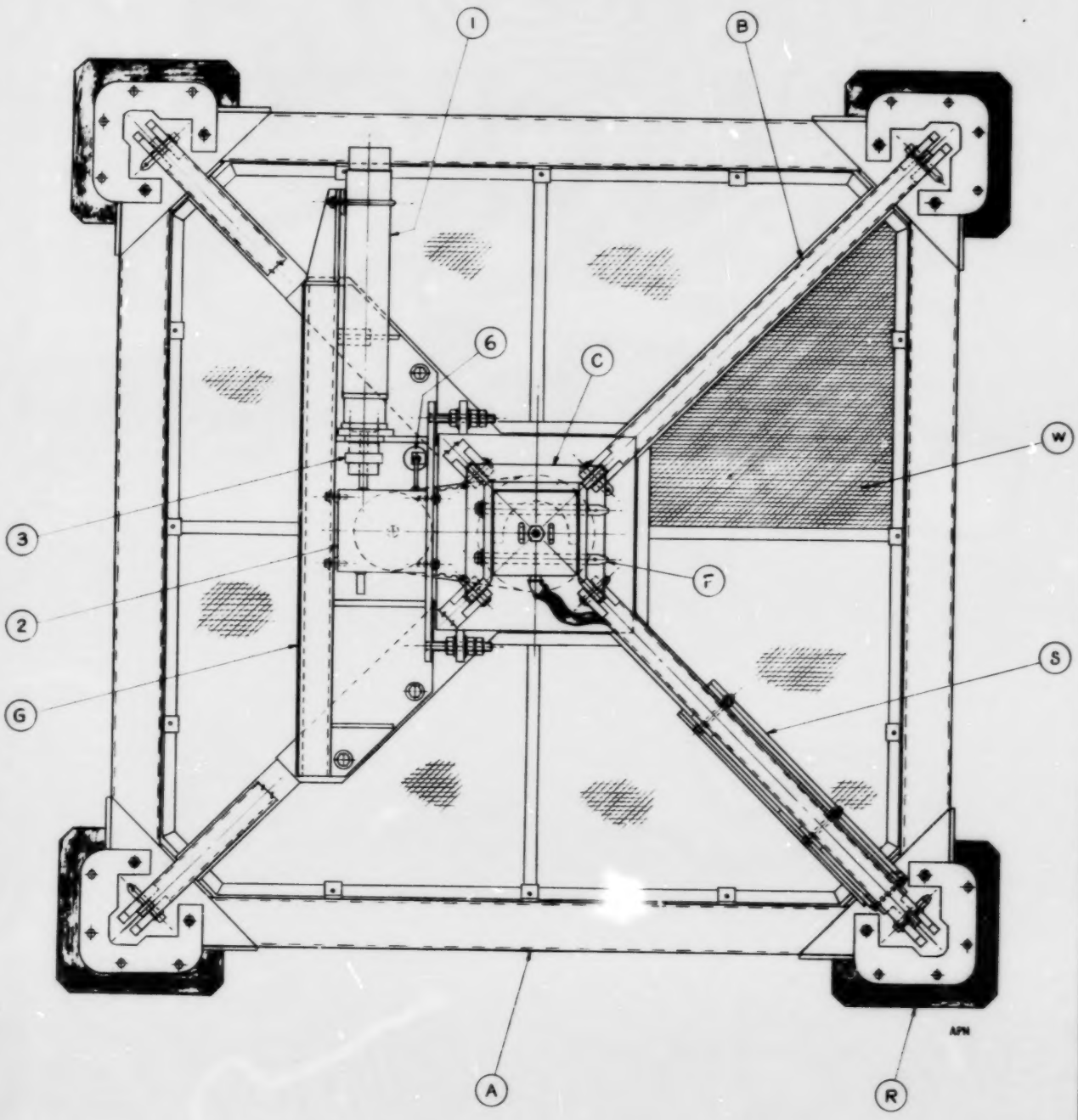
SEABED CORING DRILL

SEABED CORING DRILL PLAN VIEW

1. Drive Motor
2. Gear box
3. Coupling
6. Accumulator

A. Base frame
B. Side members
C. Top bearing support cradle
F. Main support pins
G. Drive motor mount
R. Fender
S. Pump support frame
W. Screen panel

SEABED CORING DRILL
PLAN VIEW

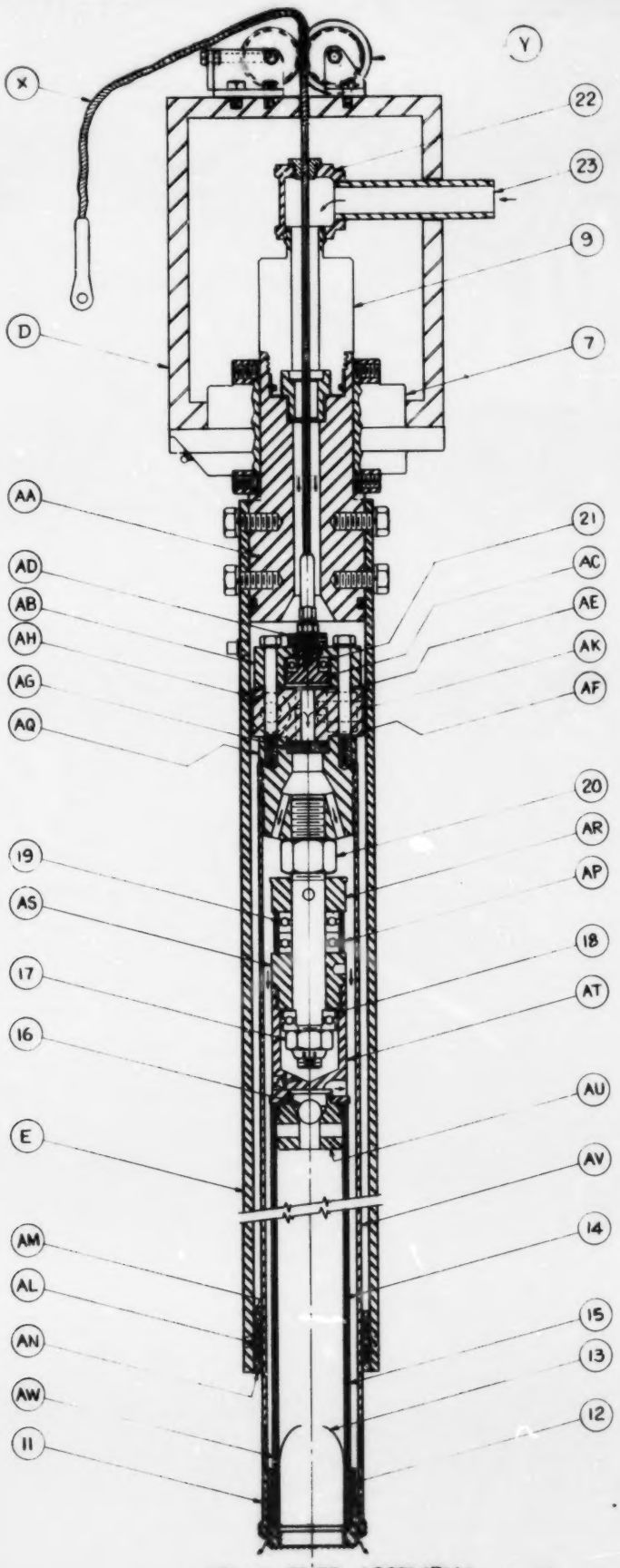


KELLY TUBE ASSEMBLY

D Swivel Head
E Kelly Tube
X Retraction Cable
Y Penetration Indicator

7. Bearing
9. Water swivel assembly
11. Drill bit
12. Stabilizer
13. Core catcher
14. Split tube
15. Core tube
16. Stainless steel ball
17. Locking mit
18. Hanger bearing
19. Thrust ball bearing
20. Locknut
21. Thrust ball bearing
22. Tee (1")
23. Nipple (1")

AA. Kelly bearing stub
AB. Cable bearing
AC. Cable bearing spindle
AD. Spindle nut
AE. Cable bearing gasket
AF. Drive block
AG. Orifice plate
AH. Drive block bearing
AK. Drive block pints
AL. Kelly seal support plate
AM. Kelly seal (outer)
AN. Kelly seal (inner)
AP. Brass ring
AQ. Drill tube head
AR. Spindle Assembly
AS. Spindle bearing
AT. Core tube cap
AU. Core tube support plug
AV. Drill tube



KELLY TUBE ASSEMBLY

ITEM	DESCRIPTION	REQ'D	UNIT WEIGHT lbs	UNIT WEIGHT kg	REMARKS
1	Drive motor Franklin submersible electric motor, super-6, 15 HP, 3 phase, 575 V, 3450 RPM	1	150	68	
2	Gear box Boston reductor. Model No. 338D Single reduction worm gear. Ratio 10:1	1	123	56	
3	Coupling SKF Flexible Coupling Half coupling #5CH-200 Half coupling #5CH-100 Rubber insert #NR5R	1			
4	Sprocket 'Morse' 1 1/4" pitch-stock timing belt sprocket. Type 4F. Sprocket No. 22XXH300 C/W QD type bushing	1			
5	Belt 'Morse' 1 1/4" pitch-stock timing belt 3" wide, 70" long, Stock No. 700XXH300	1			
6	Accumulator Bosch diaphragm type accumulator Size 21. Buna N Rubber Part No. 0531 501 533	1			
7	Bearing Sealmaster mounted roller bearing RFP 307-C	1			
8	Submersible pump (GSW) 4" submersible pump 31 stage C/W Franklin submersible electric motor. 5 HP, 3 phase, 575, V, 3450 RPM, Stock No. 500K6BJ31	1			
9	Water swivel assembly Longyear underground water swivel, Part No. 28284	1			

ITEM	DESCRIPTION	REQ'D	UNIT WEIGHT Lbs kg	REMARKS
10	Quick detachable coupling and hose assembly	1		
11	Drill bit Diamond bit, pilot crown, face discharge 45 CARAT, 10 - 15 stones per carat. OR Tungsten carbide, pilot crown face discharge	1		
12	Stabilizer (inner tube)	1		
13	Core catcher Rock type or basket type (Benthos #189 - CC)	1		
14	Split tube	1		
15	Core tube	1		
16	Stainless steel ball	1		
17	Self locking nut	1		
18	Hanger bearing	1		
19	Thurst ball bearing	2		
20	Lock nut	1		
21	Thurst ball bearing SKF #51204. ID 20 mm OD 40 mm Height 14 mm	1		
22	Tee (1") Forged steel class 2000	1		
23	Nipple (1") Sch. 80, 6" long			
24	Transformer Hammond autotransformer 3 phase 240 to 600 V Type KB KVA 45 cat. No. KB45	1		Electrosonic

ITEM	DESCRIPTION	REQ'D	UNIT WEIGHT Lbs kg	REMARKS
25	Ground fault indicator Lifeguard pump protection panel 3 phase. Ungrounded. 600 volt Cat. No. GPA-6-90	1		Federal Pioneer Limited
26	Safety switch Weatherproof safety switch - cema 3 100 AMP. 3 phase 250 V fusible Cat. No. RA3032N	1		CEB
27	Magnetic starter (drill motor) Cat. No.	1		FURNAS
28	Magnetic starter (pump motor) Cat. No. 14CF32BC71	1		FURNAS
29	Voltmeter AC voltmeter 0-600 volt Cat. No. L554SJSJ	1		Electrosonic
30	Ammeter AC Ammeter 0-50 A Cat. No. L553NTNT	1		Electrosonic
31	Ammeter AC Ammeter 0-20 A Cat. No. L553 NGNG	1		Electrosonic
32	Pushbuttons Start-stop pushbutton station, weatherproof Cat. No. 3002VX-1	2		Sylvania

ITEM	DESCRIPTION	REQ'D	REMARKS	UNIT WEIGHT Lbs	kg
A	Base frame	1		1700	771
B	Side members	4			
C	Top bearing support cradle	1			
D	Top bearing box	1			
E	Kelly tube	1			
F	Main support pins	2			
G	Drive motor mount	1			
H	Lower Bearing pillar	1			
K	Thordon water bearing	1			
L	Bearing retainer ring	1	SEE DETAILED DRAWING		
M	Rotary table pulley	1			
N	Table retainer ring	1			
P	Kelly drive plate	1			
Q	Rock shield	1			
R	Fender	4			
S	Pump support frame	1			
T	Belt guard	1			
U	Bottom kelly guard	1			
V	Top kelly guard	1			
W	Screen panel	4			
X	Retraction Cable	1			
Y	Penetration Indicator	1			

ITEM	DESCRIPTION	REQ'D	REMARKS	UNIT WEIGHT Lbs kg
AA	Kelly bearing stub	1		
AB	Cable bearing	1		
AC	Cable bearing spindle	1		
AD	Spindle nut	1		
AE	Cable bearing gasket	1		
AF	Drive block	1		
AG	Orifice plate	1		
AH	Drive block bearing	4		
AK	Drive block pins	4	SEE DETAILED DRAWING	
AL	Kelly seal support plate	1		
AM	Kelly seal (outer seal plate)	1		
AN	Kelly seal (inner seal plate)	1		
AP	Brass ring	1		
AQ	Drill tube head	1		
AR	Spindle assembly	1		
AS	Spindle bearing	1		
AT	Core tube cap	1		
AU	Core tube support plug	1		
AV	Drill tube	1		
AW	Corer retainer ring	1		

APPENDIX C

LABORATORY DRILLING TESTS

LABORATORY TESTS

(using water as flushing fluid)

Test #	Bit Type	Soil Type	Time Required	Core Recovery	Comments
1	Diamond Face Discharge	Sand & Silt	5 min	80%	Good penetration hard round core
2	Diamond Face Discharge	Sand & silt 2 rocks & 1 brick	26 min	28%	Penetrated sand and silt and first rock stuck in core catcher Bit ground its way to second rock and stopped.
3	Diamond Face Discharge	Sand & silt 2 rocks & 1 brick	30 min	10%	Rock stuck in core catcher and penetration was restricted
4	Diamond Face Discharge	Sand & silt 2 rocks & 1 brick	15 min	10%	Rock stuck in core catcher and penetration was restricted
5	Diamond Face Discharge	Sand & silt 2 rocks & 1 brick	15 min	10%	Rock stuck in core catcher and penetration was terminated
6	Diamond Face Discharge	Sand & silt 2 rocks & 1 brick	8 min	50%	Good Penetration cut rock and cored soil below rock
7	Diamond Face Discharge	Sand	2.5 min	50%	Drill started to wobble towards end of run, sand very soft
8	Diamond Face Discharge	Sand & silt and stones	7 min	53%	Soil compacted in core catcher and hindered entry into core barrel
9	Diamond Face Discharge	Sand & silt & stones	1.25 min	50%	Soil very soft and wet - drilling in same area as previous test

Laboratory Tests (using water as a flushing fluid) (Con'd)

Test #	Bit Type	Soil Type	Time Required	Core Recovery	Comments
10	Diamond Face Discharge	Sand & silt & stones	26 min	40%	Penetrated; at 0.6m rocks blocked bit
11	Diamond Face Discharge	Sand & silt & stones	14 min	0%	Continued drilling in hole from test 10; no recovery. Water leaking into inner tube, damaged "0" ring
12	Diamond Face Discharge	Sand & silt	4 min	20%	Soil plugging core catcher
13	Diamond Face Discharge	Sand & silt	6 min	20%	Soil plugging core catcher
14	Diamond Face Discharge	Sand & silt	2 min	100%	Soil moister than previous sample and did not plug
15	Diamond Face Discharge	Sand & silt	5 min	66%	Soil plugged at core catcher. Drier soil than test 14.
16	Diamond Face Discharge	Sand & silt	1 min	64%	Soil plugged same soil as test 15.
17	Diamond Face Discharge	Sand & silt	1 min	55%	Soil plugged at core catcher same as test 15
18	Diamond Face Discharge	Sand & silt	6 min	20%	Soil plugged at core catcher,very dry soil
19	Diamond Face Discharge	Sand & silt	.5 min	20%	Used greater downward thrust,soil plugging at core catcher
20	Diamond Face Discharge	Rock & sand & silt	158 min	0%	Large flushing orifice which caused pump to trip continuously from overloading

Laboratory Tests: Tests 1-22 (using water as a flushing fluid) (Con'd)
Tests 23-45 (using drilling mud as a flushing fluid)

Test #	Bit Type	Soil Type	Time Required	Core Recovery	Comments
21	Diamond Face Discharge	Sand & silt & rock	6.5 min	12%	Drill penetrated full length but only 18 cm rock recovered. Rock caught in core catcher.
22	Diamond Face Discharge	Sand & silt & rock	22 min	93%	Drilled 30 cm and had to stop due to leak in packing gland retraction cable.
23	Diamond Face Discharge	beach sand	5.5 min	28%	Soil compacting in bit, not cutting; particles rotating on diamonds
24	Diamond Face Discharge	beach sand	2.5 min	46%	Soil compacting in bit, not cutting; particles rotation on diamonds
25	Diamond Face Discharge	beach sand	9.25 min	22%	Soil compacting in bit, not cutting; particles rotation on diamonds
26	Diamond Face Discharge	concrete rock	60 min	100%	RPM reduced to 45 cm other tests 200 rpm
27	Diamond Face Discharge	concrete rock	120 min	100%	Very hard chert bolders - slow cutting
28	Diamond Face Discharge	concrete rock	73 min	100%	Penetrated 4 ft. and stopped
29	Diamond Face Discharge	clay	45 sec	43%	Bit plugged not cutting clay particles rotating on diamonds
30	Tungsten carbide face Discharge	beach sand	6 min	91%	Penetration was low drilling with 100 PSI PSI increased & drill penetration rate increased.

Laboratory Tests (using drilling mud as a flushing fluid) (Con'd)

Test #	Bit Type	Soil Type	Time Required	Core Recovery	Comments
31	Tungsten carbide face discharge	beach sand	4 min 15 sec	60%	Some of sample dropped out of core barrel as the barrel was retracted. Used two core catchers: soil & rock. This caused restriction of sample entering tube.
32	Tungsten carbide face discharge	beach sand	1 min 40 sec	82%	Loss of core inexplicable
33	Tungsten carbide face discharge	concrete	3 min 12 sec	100%	Excellent core recovery.
34	Tungsten carbide face discharge	concrete	3 min 40 sec	56%	Ran out of drilling mud. Water washed away sample.
35	Tungsten carbide face discharge	concrete	3 min 28 sec	82%	Recovery lost at end of sample possibly slipped out of core barrel. Type rock placed on sample at different locations indicated undisturbed sample.
36	Tungsten carbide face discharge	concrete	4 min	67%	Low core recovery due to rock wedged on bit and sample below ground away.
37	Tungsten carbide face discharge	concrete	5 min 11 sec	44%	Fourth hole in sample barrel
38	Tungsten carbide face discharge	clay	45 sec	56%	Clay compressed on tube and on bit. Clay expanded on contact with drilling mud.

Laboratory Tests (using drilling mud as a flushing fluid) (Con'd)

Test #	Bit Type	Soil Type	Time Required	Core Recovery	Comments
39	Tungsten carbide face discharge	clay	16 min 37 sec	19%	Used low water pressure slow penetrating sample eroded away while drilling.
40	Tungsten carbide face discharge	clay	2 min	20%	Check valve at base of core barrel not working; sample washed away.
41	Tungsten carbide face discharge	clay	1 min	80%	Taps in core hard to explain
42	Chris drill	beach sand	2 min 15 sec	44%	Not enough flushing to clear cuttings so back pressure causing erosion
43	Chris drill	beach sand	1 min	22%	Flushing increased over previous test. It is now too much, causing washing of sample.
44	Chris drill	concrete rock	20 min 6 sec	0%	Cutting edge too coarse; did not cut rock but tore out chunks which did not core
45	Chris drill	concrete rock	21 min 29 sec	0%	Same as above

APPENDIX D

SEA TRIALS

Sea Trials
from Canadian Coast Guard Ship Bartlett
Placentia Bay & St. Mary's Bay
Newfoundland

Test No.	Location	Drill Bit	Penetration	Time Required
#1	47° 19.45'N 54° 55.2'W	Tungsten Carbide (Longyear)	76 cm	20 min
#2	47° 19.45'N 54° 55.2'W	Tungsten Carbide (Christensen)	61 cm	8 min
#3	47° 19.45'N 54° 55.2'W	Tungsten Carbide (Longyear)	74 cm	16 min
#4	47° 19.45'N 54° 55.2'W	Tungsten Carbide (Longyear)	137 cm	17 min
#5	46° 55.5'N 53° 34.2'W	Diamond Face Discharge (Longyear)	152 cm	50 sec
#6	46° 55.5'N 53° 34.2'W	Tungsten Carbide (Longyear	152 cm	1 min 30 sec
#7	46° 55.5'N 53° 34.2'W	Tungsten Carbide (Longyear)	74 cm	2 min
#8	46° 55.5'N 53° 34.2'W	Diamond Face Discharge (Longyear)	94 cm	7 min
#9	46° 55.5'N 53° 34.2'W	Diamond Face Discharge (Longyear)	127 cm	24 min
#10	46° 55.5'N 53° 34.2'W	Diamond Face Discharge (Longyear)	51 cm	1 min
#11	46° 55.5'N 53° 34.2'W	Diamond Face Discharge (Longyear)	3 cm	10 sec

Core Recovery	Soil Type	Comments
10%	Course gravel	Mud system not working inner tube rotating. Drill rocking.
10%	Course gravel with sand & silt	Mud system not working inner tube rotating. Drill rocking.
10%	Course gravel with silt	Mud system not working inner tube rotating. Drill rocking.
10%	Course gravel	Mud system not working inner tube rotating. Drill rocking.
10%	Fine sand	Drilling mud viscosity too low. Drill rocking.
20%	Fine sand	Drilling mud viscosity too low. Drill rocking. Retraction cable broke, difficulty recovering drill.
5%	Cobble	Cobble plugged on core catcher. Drill rocking
10%	Cobble with sand	Cobble plugged at core catcher. Drill rocking.
30%	Cobble with sand	Cobble plugged at core catcher. Drill rocking. Hoist cable broke mud hose.
5%	Cobble with sand	Cobble plugged at core catcher. Drill rocking. Drill tripped out, electrical fault.
-	-	Drill tripped out electrical fault.

POOR

QUALITY

ORIGINAL